[0009] Exemplary applications of the subject matter of the disclosure include, but are not limited to:

- Multi-step catalysis
- Assembly-line biosynthesis
- Tissue engineering
- Soft-materials with unique bulk physical properties dictated by protein composition

[0010] Advantages of the subject matter of the disclosure include, but are not limited to:

- Generalizable strategy through which any protein can be incorporated into polymeric structure
- Protein polymer materials with tailorable molecular weight distributions and architecture
- Oligonucleotide length can be tailored to define specific inter-protein distance

[0011] Accordingly, in some aspects, the disclosure provides a method of making a protein polymer comprising contacting (a) a first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (V) and a second domain (W); and (b) a second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (V') and a second domain (W'), wherein (i) V is sufficiently complementary to V' to hybridize under appropriate conditions and (ii) W is sufficiently complementary to W' to hybridize under appropriate conditions, and wherein the contacting results in V hybridizing to V', and W hybridizing to W', thereby making the protein polymer. –In some aspects, the disclosure provides a method of making a protein polymer comprising contacting: (a) a plurality of first protein monomers, each first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (V) and a second domain (W); and (b) a plurality of second protein monomers, each second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (V') and a second domain (W'), wherein (i) V is sufficiently complementary to V' to hybridize under appropriate conditions and (ii) W is sufficiently complementary to W' to hybridize under appropriate conditions, and wherein the contacting results in V hybridizing to V' and W hybridizing to W', thereby making the protein polymer. In some examples, the contacting allows W to hybridize to W'. In some embodiments, the first protein and the second protein are the same. In further examples, the first protein and the second protein are different. In some examples, the first protein and the second protein are subunits of a multimeric protein. In some examples, the first oligonucleotide is attached to the first protein via a lysine or cysteine on the surface of the first protein. In some examples, the first oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof. In further examples, V is from about 10-100 nucleotides in length. In some examples, W is from about 10-100 nucleotides in length. In some examples, the second oligonucleotide is attached to the second protein via a lysine or cysteine on the surface of the second protein. In further examples, the second oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof. In some examples, V' is from about 10-100 nucleotides in length. In some examples, W' is from about 10-100 nucleotides in length. In some examples, the protein polymer is a hydrogel or a therapeutic. In further examples, the therapeutic is an antibody, a cell penetrating peptide, a viral capsid, an intrinsically disordered protein, a lectin, or a membrane protein.

[0012] In some aspects, the disclosure provides a method of making a protein polymer comprising contacting (a) a first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a first hairpin structure; (b) a second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (Y), a second domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a second hairpin structure; and (c) an initiator oligonucleotide comprising a first domain (Y) and a second domain (X'); wherein the contacting results in (i) X' of the initiator oligonucleotide hybridizing to X of the first oligonucleotide and Y of the initiator oligonucleotide displacing Y of the first oligonucleotide, thereby opening the first hairpin structure and (ii) Z' of the second oligonucleotide hybridizing to Z of the first oligonucleotide thereby opening the second hairpin structure, and thereby making the protein polymer. In some aspects, the disclosure provides a method of making a protein polymer comprising contacting: (a) a plurality of first protein monomers, each first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a first hairpin structure; (b) a plurality of second protein monomers, each second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (Y), a second domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a second hairpin structure; and (c) an initiator oligonucleotide comprising a first domain (Y) and a second domain (X'); wherein the contacting results in (i) X' of the initiator oligonucleotide hybridizing to X of the first oligonucleotide and Y of the initiator oligonucleotide displacing Y of the first oligonucleotide, thereby opening the first hairpin structure and (ii) Z' of the second oligonucleotide hybridizing to Z of the first oligonucleotide thereby opening the second hairpin structure, and thereby making the protein polymer. In some examples, the first protein and the second protein are the same. In some examples, the first protein and the second protein are different. In further examples, the first protein and the second protein are subunits of a multimeric protein. In some examples, the first oligonucleotide is attached to the first protein via a lysine or cysteine on the surface of the first protein. In some examples, the first oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof. In further examples, X of the first oligonucleotide is from about 2-20 nucleotides in length. In some examples, Y' of the first oligonucleotide is from about 12-80

nucleotides in length. In some examples, Z of the first oligonucleotide is from about 2-20 nucleotides in length. In some examples, Y of the first oligonucleotide is from about 12-80 nucleotides in length. In further examples, the second oligonucleotide is attached to the second protein via a lysine or cysteine on the surface of the second protein. In still further examples, the second oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof. In some examples, Y of the second oligonucleotide is from about 12-80 nucleotides in length. In some examples, X' of the second oligonucleotide is from about 2-20 nucleotides in length. In some examples, Y' of the second polynucleotide is from about 12-80 nucleotides in length. In some examples, Z' of the second polynucleotide is from about 2-20 nucleotides in length. In further examples, the protein polymer is a hydrogel or a therapeutic. In various examples, the therapeutic is an antibody, a cell penetrating peptide, a viral capsid, an intrinsically disordered protein, a lectin, or a membrane protein. In some examples, a method of the disclosure further comprises adding a third protein monomer comprising a third protein to which a third oligonucleotide is attached, the third oligonucleotide comprising a first domain (X), a second

CLAIMS

1. A method of making a protein polymer comprising contacting:

(a) a first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (V) and a second domain (W); and

(b) a second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (V') and a second domain (W'),

wherein (i) V is sufficiently complementary to V' to hybridize under appropriate conditions and (ii) W is sufficiently complementary to W' to hybridize under appropriate conditions, and wherein the contacting results in V hybridizing to V' and W hybridizing to W',

thereby making the protein polymer.

2. A method of making a protein polymer comprising contacting:

(a) a plurality of first protein monomers, each first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (V) and a second domain (W); and

(b) a plurality of second protein monomers, each second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (V') and a second domain (W'),

wherein (i) V is sufficiently complementary to V' to hybridize under appropriate conditions and (ii) W is sufficiently complementary to W' to hybridize under appropriate conditions, and wherein the contacting results in V hybridizing to V' and W hybridizing to W',

thereby making the protein polymer.

~~2. The method of claim 1, wherein the contacting allows W to hybridize to W'.~~

3. The method of claim 1 or claim 2, wherein the first protein and the second protein are the same.

4. The method of claim 1 or claim 2, wherein the first protein and the second protein are different.

5. The method of any one of claims 1-4, wherein:

(a) the first protein and the second protein are subunits of a multimeric protein; and/or

(b) the first oligonucleotide is attached to the first protein via a lysine or cysteine on the surface of the first protein; and/or

(c) the first oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof; and/or

(d) V is from 10-100 nucleotides in length; and/or

(e) W is from 10-100 nucleotides in length; and/or

(f) the second oligonucleotide is attached to the second protein via a lysine or cysteine on the surface of the second protein; and/or

(g) the second oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof; and/or

(h) V' is from 10-100 nucleotides in length; and/or

(i) W' is from 10-100 nucleotides in length.

~~6. The method of any one of claims 1-5, wherein the protein polymer is a hydrogel or a therapeutic, optionally wherein the therapeutic is an antibody, a cell penetrating peptide, a viral capsid, an intrinsically disordered protein, a lectin, or a membrane protein.~~

6. The method of any one of claims 2-5, wherein equimolar ratios of the plurality of first protein monomers and the plurality of second protein monomers are contacted.

7. A method of making a protein polymer comprising contacting:

(a) a first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a first hairpin structure;

(b) a second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (Y), a second

domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a second hairpin structure; and

(c) an initiator oligonucleotide comprising a first domain (Y) and a second domain (X');

wherein the contacting results in (i) X' of the initiator oligonucleotide hybridizing to X of the first oligonucleotide and Y of the initiator oligonucleotide displacing Y of the first oligonucleotide, thereby opening the first hairpin structure and (ii) Z' of the second oligonucleotide hybridizing to Z of the first oligonucleotide thereby opening the second hairpin structure, and

thereby making the protein polymer.

8. A method of making a protein polymer comprising contacting:

(a) a plurality of first protein monomers, each first protein monomer comprising a first protein to which a first oligonucleotide is attached, the first oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a first hairpin structure;

(b) a plurality of second protein monomers, each second protein monomer comprising a second protein to which a second oligonucleotide is attached, the second oligonucleotide comprising a first domain (Y), a second domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a second hairpin structure; and

(c) an initiator oligonucleotide comprising a first domain (Y) and a second domain (X');

wherein the contacting results in (i) X' of the initiator oligonucleotide hybridizing to X of the first oligonucleotide and Y of the initiator oligonucleotide displacing Y of the first oligonucleotide, thereby opening the first hairpin structure and (ii) Z' of the second oligonucleotide hybridizing to Z of the first oligonucleotide thereby opening the second hairpin structure, and

thereby making the protein polymer.

~~8~~9. The method of claim 7 or claim 8, wherein the first protein and the second protein are the same.

~~9~~10. The method of claim 7 or claim 8, wherein the first protein and the second protein are different.

11. The method of any one of claims 8-10, wherein equimolar ratios of the plurality of first protein monomers and the plurality of second protein monomers are contacted.

~~10~~12. The method of any one of claims 7-~~9~~11, wherein:

(a) the first protein and the second protein are subunits of a multimeric protein; and/or

(b) the first oligonucleotide is attached to the first protein via a lysine or cysteine on the surface of the first protein; and/or

(c) the first oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof; and/or

(d) X of the first oligonucleotide is from 2-20 nucleotides in length; and/or

(e) Y' of the first oligonucleotide is from 12-80 nucleotides in length; and/or

(f) Z of the first oligonucleotide is from 2-20 nucleotides in length; and/or

(g) Y of the first oligonucleotide is from 12-80 nucleotides in length.

~~11~~13. The method of any one of claims 7-~~10~~12, wherein:

(a) the second oligonucleotide is attached to the second protein via a lysine or cysteine on the surface of the second protein; and/or

(b) the second oligonucleotide is DNA, RNA, a combination thereof, or a modified form thereof; and/or

(c) Y of the second oligonucleotide is from 12-80 nucleotides in length; and/or

(d) X' of the second oligonucleotide is from 2-20 nucleotides in length; and/or

(e) Y' of the second polynucleotide is from 12-80 nucleotides in length; and/or

(f) Z' of the second polynucleotide is from 2-20 nucleotides in length.

~~12~~14. The method of any one of claims ~~7~~1-~~11~~13, wherein the protein polymer is a hydrogel or a therapeutic, optionally wherein the therapeutic is an antibody, a cell penetrating peptide, a viral capsid, an intrinsically disordered protein, a lectin, or a membrane protein.

~~13~~15. The method of any one of claims 7-~~12~~14, further comprising adding a third protein monomer comprising a third protein to which a third oligonucleotide is attached, the third oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a third hairpin structure.

16. The method of any one of claims 8-14, further comprising adding a plurality of third protein monomers, each third protein monomer comprising a third protein to which a third oligonucleotide is attached, the third oligonucleotide comprising a first domain (X), a second domain (Y'), a third domain (Z), and a fourth domain (Y), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a third hairpin structure.

~~14~~17. The method of claim ~~13~~15 or claim 16, wherein the third protein is identical to the first protein.

~~15~~18. The method of claim ~~13~~15 or claim 16, wherein the third protein is identical to the second protein.

~~16~~19. The method of any one of claims 7-~~15~~18, further comprising adding a fourth protein monomer comprising a fourth protein to which a fourth oligonucleotide is attached, the fourth oligonucleotide comprising a first domain (Y), a second domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a fourth hairpin structure.

20. The method of any one of claims 8-18, further comprising adding a plurality of fourth protein monomers, each fourth protein monomer comprising a fourth protein to which a fourth oligonucleotide is attached, the fourth oligonucleotide comprising a first domain (Y), a second domain (X'), a third domain (Y'), and a fourth domain (Z'), wherein Y is sufficiently complementary to Y' to hybridize under appropriate conditions to produce a fourth hairpin structure.

~~17~~21. The method of claim ~~16~~19 or claim 20, wherein the fourth protein is identical to the first protein.

~~18~~22. The method of claim ~~16~~19 or claim 20, wherein the fourth protein is identical to the second protein.

23. The method of any one of claims 20-22, wherein equimolar ratios of the plurality of third protein monomers and the plurality of fourth protein monomers are added.

24. The method of any one of claims 8-23, wherein the amount of the initiator oligonucleotide is 0.2 equivalents to 2 equivalents, or 0.2 equivalents to 1.6 equivalents, or 0.2 to 1.4 equivalents, or 0.2 to 1.2 equivalents, or 0.2 to 1.0 equivalents, or 0.2 to 0.8 equivalents, or 0.2 to 0.6 equivalents, or 0.2 to 0.4 equivalents.

25. The method of any one of claims 8-23, wherein the amount of the initiator oligonucleotide is or is at least 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, or 2.0 equivalents.

26. The method of any one of claims 8-23, wherein the amount of the initiator oligonucleotide is less than 2.0, 1.8, 1.6, 1.4, 1.2, 1.0, 0.8, 0.6, 0.4, or 0.2 equivalents.

~~19~~27. A protein polymer which is a therapeutic ~~of any one of~~as defined in claim 14~~s 1-18~~ for use in therapy.

~~20~~28. A composition comprising the protein polymer of any one of claims 1-~~18~~ 27 and a physiologically acceptable carrier.